ACEEE Int. J. on Electrical and Power Engineering , Vol. 4, No. 3, November 2013

PV Hybrid System with DSTATCOM for Residential Applications

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***Abstract*- Now a days PV based energy systems are playing a vital role among all the renewable energy sourcesin our day to day life.Proper control should be required to meet the exact load conditions such that it should satisfy the non-linear nature of both the solar irradiance and load. In this paper, a battery is also incorporated along with the PV system to meet the necessary drop due to change in weather conditions. Here, a proper control is achieved by using DSTATCOM to compensate the reactive power. This paper proposes an advanced technique of PWM to generate the gating pulses and applied to a Cascaded H-Bridge multilevel inverter to improve the voltage quality. Here, the entire system is designed to meet the load of Mogulthur (W.G.Dt. Andhra Pradesh). Simulation results are presented through Matlab/Simulink by taking different cases into consideration**.

***Index Terms:*- PV system, Stand alone system, DSTATCOM, Power quality.**

I. Introduction

Today PV based power generation systems are becoming more and more popular, with the increase of energy demand and the concern of environmental pollution around the world. One of the inherent advantages of PV electricity generation is the absence of any mechanical parts. Professionally installed PV arrays are characterized by a long service lifetime, exceeding 20 years, high reliability, and low maintenance requirements, which are highly desirable for remote area power supplies. In sunny locations, PV generators compare favourably with wind generators, despite the higher investment cost for PV modules per peak Watt. Wind generators require regular maintenance and are susceptible to damage in strong winds [2]. However, PV power fluctuates depending on the weather conditions, season, and geographic location, and may cause problems like voltage fluctuation and large frequency deviation in e lectric power system operation [2]. Usually, an energy storage system (i.e., battery) is used to smooth the PV output power fluctuations and then the smoothed power is supplied to the utility [1].Power vs voltage characteristics of PV shows that PV can generate maximum power at particular voltage called as V_{mpp} at corresponding level of irradiance. For best utilization, the PV cells must be operated at their maximum power point. According to perturb and observe (P&O) algorithm, maximum power point tracking (MPPT) is achieved by adjusting the terminal voltage of PV panels to V_{mpp} .

To supply a qualitative power is the main challenge in a stand-alone system. Voltage variations, flickers and harmonic generation are the major power quality (PQ) problems that occur in solar energy conversion system .Those power quality problems may not be tolerated by the customers and hence require mitigation techniques[5].One of the most promising applications of renewable energy technology is the installation of hybrid energy systems in remote areas, where the cost of grid extension is prohibitive and the price for fuel drastically increases with the remoteness of the location. Renewable energy sources, such as photovoltaic (PV), wind energy, or small-scale hydro, provide a realistic alternative to engine-driven generators for electricity generation in remote areas. [3].

This paper concentrates on the control and application of PV-battery hybrid energy systems, which account for the majority of systems installed today. A system to provide uninterrupted power which integrates PV, battery and inverter has been considered. In general four different system configurations are widely developed in stand-alone PV power applications: the centralized inverter system, the string inverter system, the multi-string inverter system and the module-integrated inverter system. [4]. Mostly centralized inverter system can be employed for small-scale distributed generation (DG) systems, such as residential power applications. Residential loads are mostly single phase loads; Therefore, in this paper single phase cascaded H-bridge five level inverter is used in the conversion of photovoltaic voltage (D.C) to our Domestic voltage (A.C). Here an advanced technique of unipolar phase disposition pulse width modulation is provided to nullify the switching losses and to improve the output voltage quality.

II. System Description

Photovoltaic inverters become more and more widespread within both private and commercial circles. The isolated power utility used in this paper is shown in Fig. 1. This is actually a parallel PV-battery hybrid power system consisted of a PV generator, battery, a bidirectional converter (MPPT for V), multilevel inverter, DSTATCOM and ac load. In addition, it is assumed that the isolated power utility is not connected to any large power utility and it is always independently operated as a stand-alone system. The battery supplies the load demand when no PV power/few PV power is available.

DOI: 01.IJEPE.4.3. 1337

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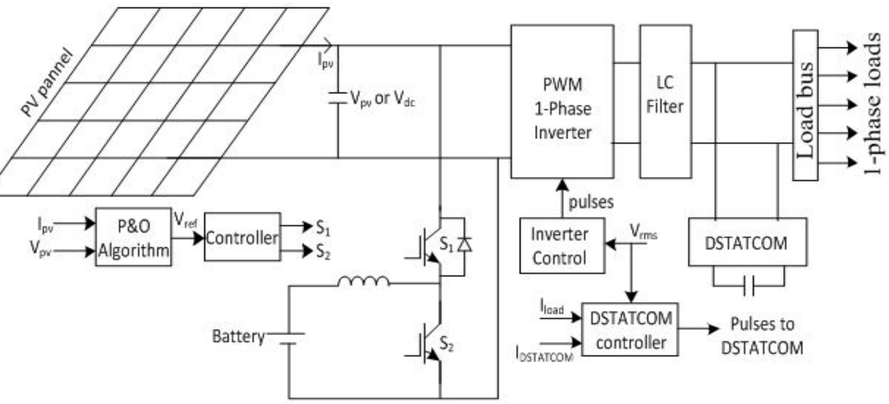

Fig. 1: PV based hybrid power generation system

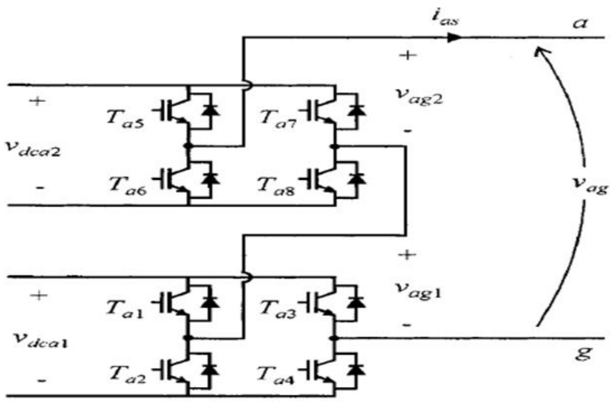

Fig 1(a) Block Diagram of H-bridge inverter

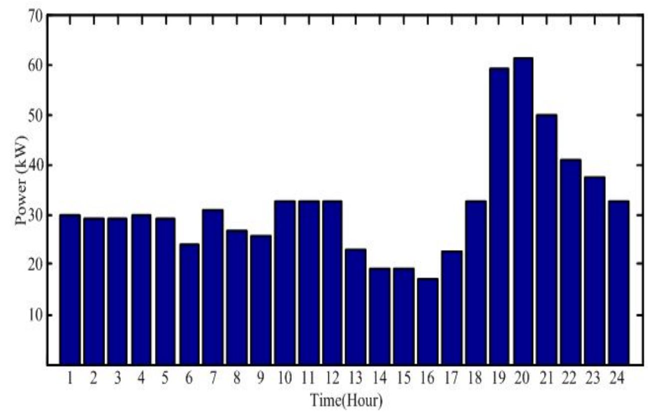

Fig. 2: Load profile of Mogultur village, Andhrapradesh, India

Cascaded Multilevel H-Bridge Inverter:

As seen in the structure of cascaded H-Bridge Invertors in fig.1(a), each H-bridge inverter needs a separate or isolated DC source. This requirement makes the cascaded inverter a perfect fit for utility interface of renewable energy sources such as photo voltaic or fuel cells where isolated dc sources naturally exist. Since the cascaded inverter eliminates custom designed transformers, a tremendous cost reduction can be expected.

AC load considered in this paper is taken from Mogultur village, Narspurmandal, West Godavari district, Andhrapradesh state, India. The profile of load for 24 hours is shown in Fig. 2. According to this load, maximum 61.28kW power supply is required to drive the load. However, solar irradiance will not meet 1000W/m^2 in Andhrapradesh. Hence, for safe and reliable operation, selection of solar power should be more than 61.28kW.

The required rms of single phase is 230V ac50 Hz frequency. To avoid over modulation index, during reactive power and considering loses at LC filter minimum 300V dc is required to maintain 230V rms at load bus. Hence, in this paper, minimum dc link is considered as 300V. For best utilization, the PV cells must be operated at their maximum power point. To extract the maximum power from PV, PV system should operate at voltage corresponding to maximum power, this can achieve by power electronics converter which can regulate the dc link voltage. Considered minimum solar irradiance is 200W/m^2. So that selected PV system should operate 300V at 200W/m^2 irradiance. The PV module is the result of associating a group of PV cells connected in series and parallel. The TSM305 PV model is available in the market, and it is considered in this paper to implement in Matlab/simulink. In this paper a PV array consist of 9 PV modules. Each module having open circuit voltage as 43.20V, short circuit current is 9.49A, voltage at maximum power (V_{mpp}) is 36V and current at maximum power is 8.47. The PV cell is shown in Fig. 3(a) and power vs voltage curves of one PV array are shown in Fig. 3(b) with different level of solar irradiance. Fig. 3(b) shows that PV can generate maximum power at particular voltage at corresponding level of irradiance. According to perturb and observe (P&O) algorithm, MPPT is achieved by adjusting the terminal voltage of PV panels to V_{mpp}. In this paper PV panel is directly connected to the dc bus and P&O algorithm for MPPT is incorporated using dc-dc converter (connected between battery and dc-link). Therefore, dc-dc converter not only controls the dc-link voltage but also acts a MPPT and hence additional MPPT circuit for PV is not required.

Since 9 modules are connected in series, V_{mpp} of PV arrays will vary from 300 to 324V according to solar irradiance (G) varies from 200 to 1000W/m^2. Vmpp which is output of P&O algorithm will then act as reference dc-link voltage to dc-dc converter control. The maximum power rating of each array is 2745Wand hence by using 29 arrays in parallel, therefore maximum solar power generation is nearly 80 kW. This can maintain the load demand. In case of PV power is more than the load demand, the surplus power will dump into the battery. Hence the selection of battery is depends on

DOI: 01.IJEPE.4.3.1337

maximum surplus power from PV. However, the minimum load is 17.25kW. Therefore maximum surplus power will be 62.75kW. Considering reliability and safe operation of the system considered 65kW battery which is available in the market.

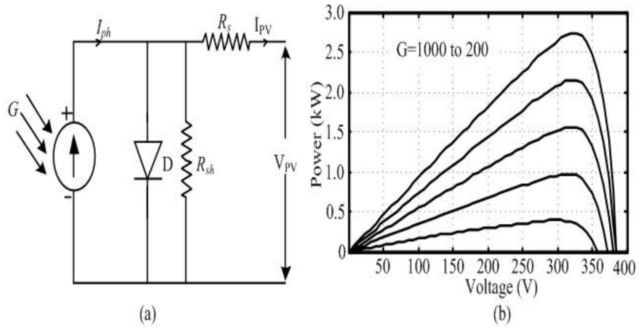

Fig. 3: (a) single cell model; (b) P-V curve of one PV array

The battery is connected to the dc-link through a dc- dc bidirectional buck-boost converter. Using bidirectional buck-boost converter, the battery voltage can be kept lower as compared to reference dc-link voltage and hence less number of batteries need to be connected in series. In the proposed system battery voltage is kept at about 180 V (i.e 15 batteries each 12V are connected in series). Hence in the design of dc-dc converter control, limiter is connected after generating Vmpp by P&O algorithm which limits the reference voltage of dc-link between 324 V to 300 V. The lower limit of dc voltage (i.e 300V) corresponds to 200 W/m2 irradiance. Hence, for irradiance below 200 W/m2, P&O algorithm acts as constant voltage MPPT algorithm. This is helpful to operate the system during night time and under non sunny days. Matlab based implementation of P&O algorithm is shown in Fig. 3(c). In Fig. 3, inputs are voltage of PV panel and current of PV system. Steep change is decided based on change in power. The output of the system is V_{mpp} and it is treated as input to controller of dc-dc converter, hence extra converter to track maximum power from PV is not required.

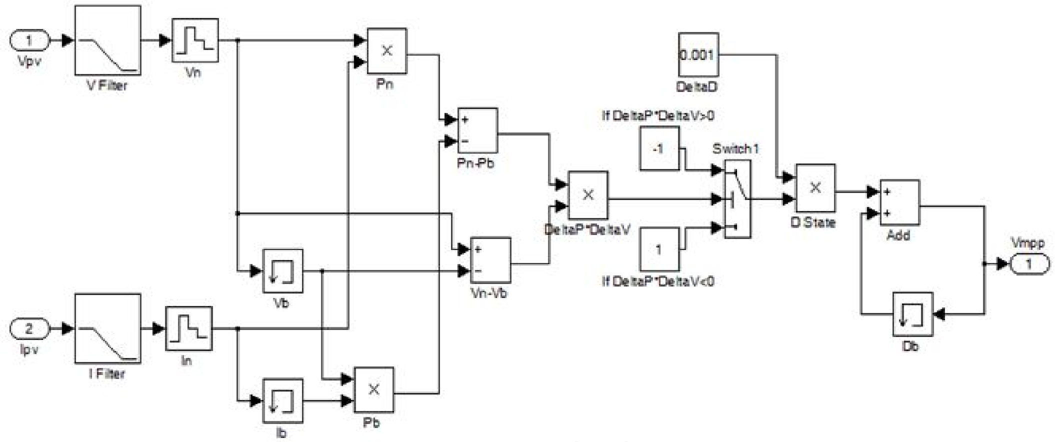

Fig. 3: (c) P&O algorithm

III. Control of DC Link and AC Bus Voltage

Due to variations in the solar irradiation and load; dc-link voltage varies because of power mismatch between sources and load. Hence, it is required to maintain dc-link voltage constant irrespective of variations in solar irradiation and load. Battery is used to maintain the power balance of the system. In this paper, bidirectional buck-boost converter is connected between dc-link and battery to maintain the charging and discharging process corresponding to changes in load and generation power. Hence proper controller design is required to control the dc-link. The controller of buck-boost converter is shown in Fig. 4 (a), where two switches are used to control the charging and discharging process. Reference dc-link voltage which is generated from P&O algorithm is compared to dc-link voltage and error is fed to proportional plus integral (PI) controller. The output of PI controller gives the reference battery current. Pulses for two switches (dc-dc converter) are generated with the help of hysteresis current control loop by comparing reference and actual currents of battery.

In order to obtain the required pulses an unipolar phase disposition technique is developed and by using necessary logic gates and the obtained pulses are shown below to inverter control as shown in Fig. 4 (b). Modulation index generated by PI controller is feed to PWM generator so that required pulses are generated by PWM generator according to reference voltage of AC bus (i.e., 230). As far as frequency of output ac voltage is concerned, it can be maintained at specified value by choosing the frequency of sinusoidal reference signal while generating the PWM pulses

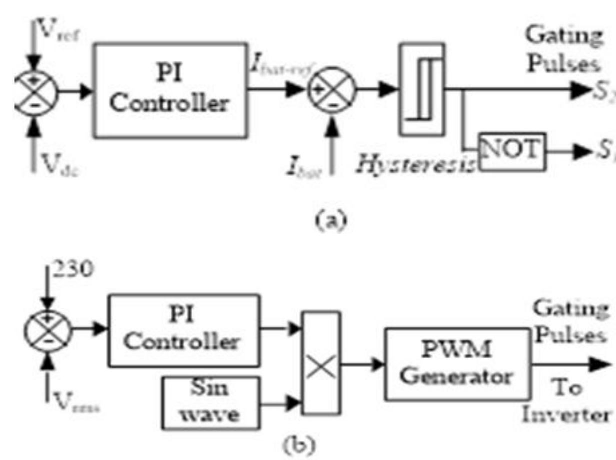

Fig. 4: (a) Bidirectional dc –dc converter control, (b) Inverter control

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Block diagram of PWM Generator

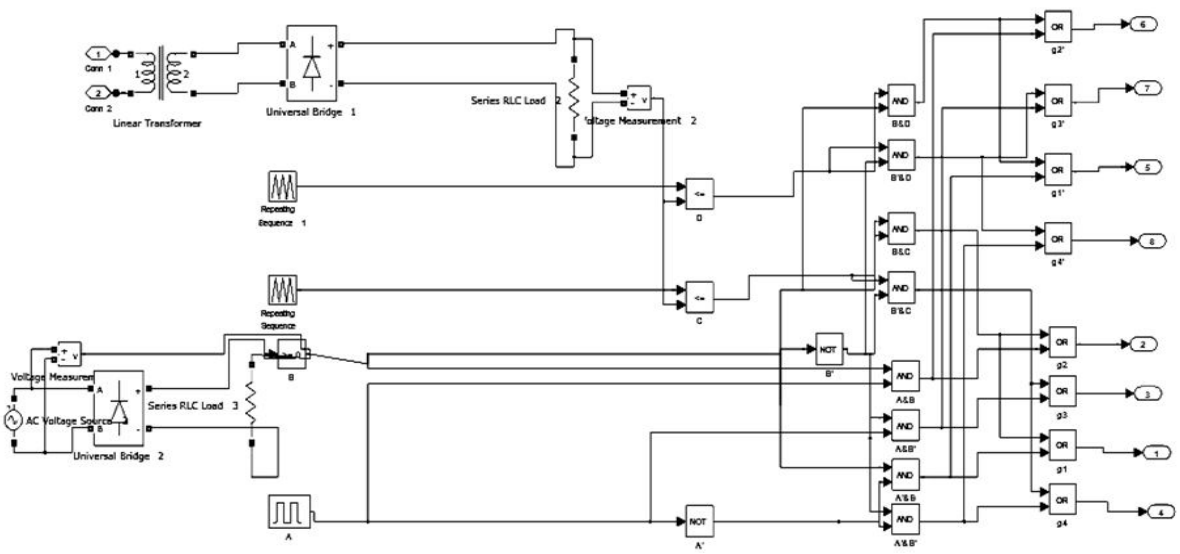

Figure 5 Logic applied to generate pulses

Here, in each H-bridge, 4 power devices are operated at 2 different frequencies i.e., 2 are commutated at low frequency(i.e., fundamental) while other 2 are pulse width modulated at high frequency causes problem of differential switching losses among the switches. So proper logic is implemented in order to give the firing pulses and is shown in (fig.5) The gating pattern generated is shown (fig.9) So, to eliminate this, a hybrid PWM controller is used to mix

a) Sequential signal

b) Low frequency PWM

c) High frequency phase disposition SPWM and to generate appropriate pulses for cascaded inverter and the appropriate

results are shown in fig 9(a) and 9(b)

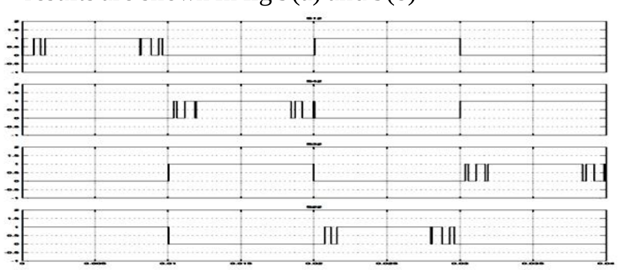

Fig.9(a) Gating pulses for first bridge

Sg11, Sg41 , Sg31 , Sg21

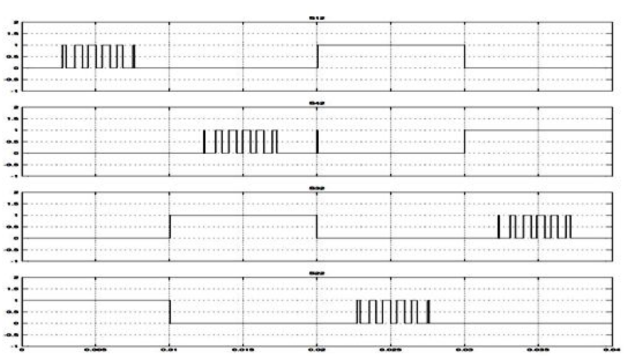

Fig. 9(b)Gating pulses for second bridge

Sg12 , Sg42 , Sg32 , Sg22

Generally home loads are consuming reactive power, but PV-Battery cannot supply reactive power because of those are DC sources. In this condition alternate support is required to either supply or compensate the required reactive power by the load. This can achieve by using DSTATCOM [6]. In this paper, DSTATCOM is connected after LC filter and propose controller to compensate required reactive power by load. The controller for DSTATCOM is shown in Fig. 6. For the DSTATCOM controller, compared both reactive powers by load and DSTATCOM The error is given to PI controller and it is generated required modulation index. Pulses are generated with PWM generator by using modulation index generated by PI controller. Generated PWM signals will go to DSTATCOM.

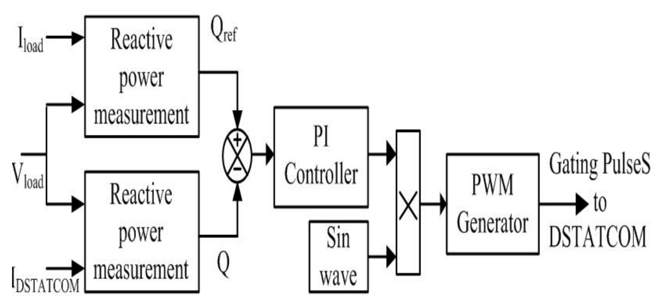

Fig. 6: DSTATCOM control

IV. Results and Discussions

The results are carried out by Matlab/simulink and those are discussed by following case studies.

Case A: Change in Solar Irradiance:

Considered solar irradiance reduced from 1000 to 650W/m^2 at t=4sec. as shown in Fig. 6 (a). For this change, P&O algorithm will track voltage at maximum power (V_{ref}) as shown in Fig. 6(b). Corresponding maximum and power generated by PV system is shown in Fig. 6(c). From Fig. 6(c), it shows the dc to dc converter helps to track the maximum power from

DOI: 01.IJEPE.4.3.1337

ACEEE Int. J. on Electrical and Power Engineering , Vol. 4, No. 3, November 2013

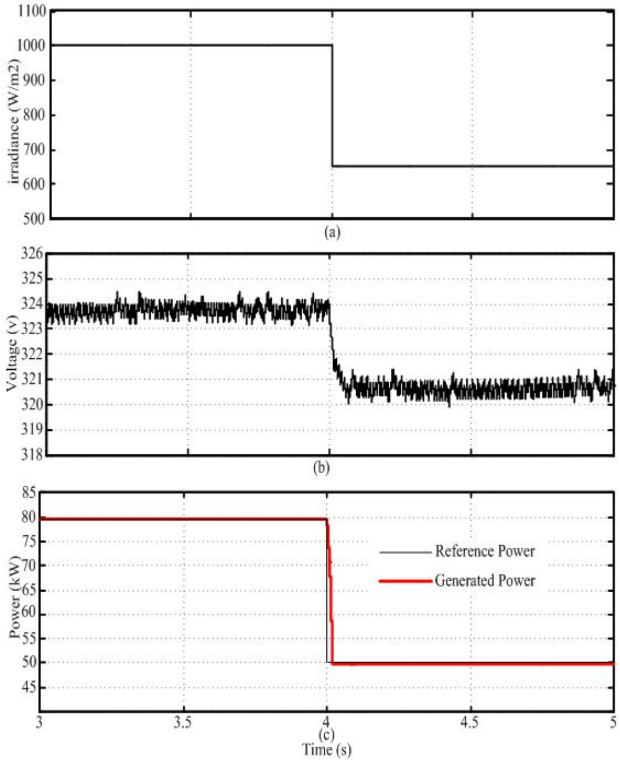

Fig. 6: (a) change in irradiance, (b) V_{ref} generated by P&O, (c) PV powers

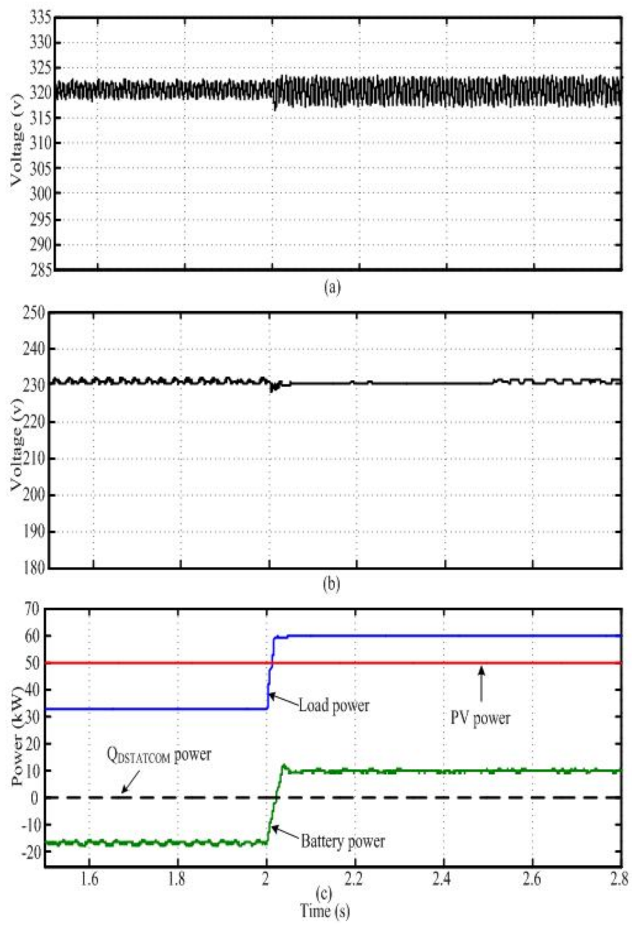

Fig. 7: (a) dc link voltage, (b) rms voltage at AC bus, (c) Powers

PV system. Therefore proposed dc to dc convert not only regulates the dc link voltage it also act as MPPT for PV system. Hence, extra MPPT is not required for PV.

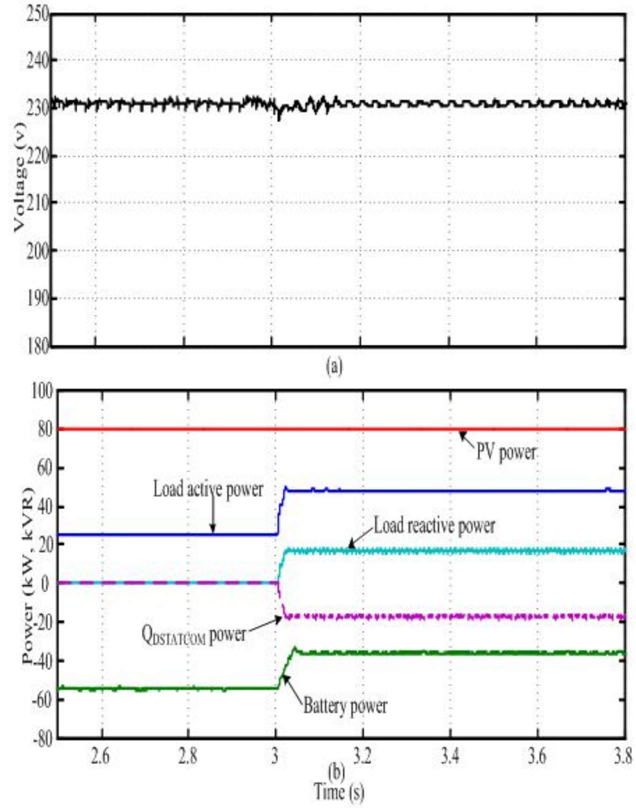

Fig. 8: (a) rms voltage at AC bus, (b) Powers

Case B**:** Change in Load Power (Active power):

Now considered load changes from 32.78kW to 59.26kW at t= 2sec. (corresponding 18th and 19th hour as shown in Fig. 2). Maximum load change is considered to show the response of dc-link and AC rms voltage, however, practically solar irradiance is almost zero during this time period. In this case, we considered irradiance is at 650W/m^2in simulation results. During this change, dc link voltage is stable and it is depicted in Fig. 7 (a). Corresponding rms voltage at AC bus and various powers in the system is shown in Fig. 7(b) and (c) respectively. From Fig. 7 (a) and (b) it is represents the system maintaining good power quality.

Case C**:** Reactive Power Compensation:

In this case, considered irradiance at maximum level and applied 20 kVAR along with 20kW power to the load at t= 3sec. before, t=3 sec. the active power consumed by load is 25kW. Therefore after t=3 sec, power factor will be 0.8 at load bus. In this scenario, DSTATCOM compensate reactive power required by the load so that no need to supply reactive power by inverter which is connected to dc link. The corresponding rms voltage and various powers included in system are shown in Fig. 8(a) and (b) respectively.

From Fig 8(a), it is observe that, the output phase rms voltage is almost immune to fluctuations. The rms value of output ac voltage may not give the clear picture of voltage waveform in the transient condition; hence instantaneous current and voltage are presented in Fig. 9 (a) and (b)

DOI: 01.IJEPE.4.3.1337

ACEEE Int. J. on Electrical and Power Engineering , Vol. 4, No. 3, November 2013

respectively. From Fig. 9 (b) at t=3sec. it is seen that there is no significant rise in the voltage waveform during load transient. The total harmonic distortion (THD) in the output ac voltage is about 5% in all the three phases. Hence it can be established that with the help of PWM switching and a passive LC filter, a satisfactory quality of voltage can be supplied to the loads. The frequency at AC bus is shown in Fig. 10, From Fig. 10, there is no change in frequency with respect to changes in load as well as irradiance.

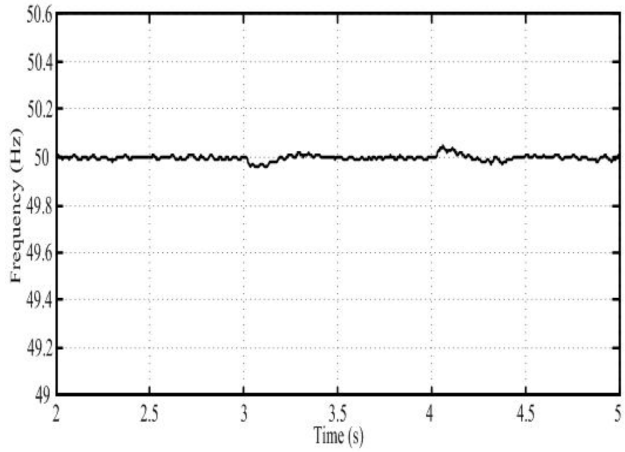

Fig. 10: Response of frequency

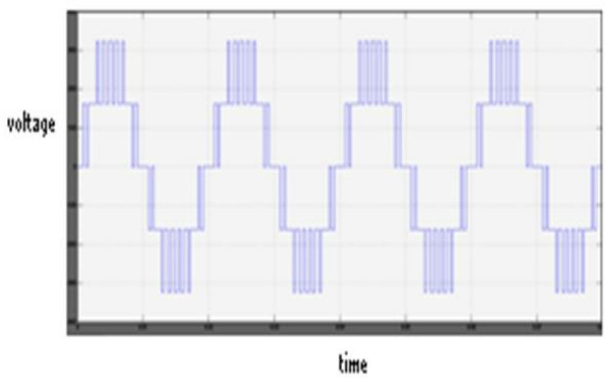

Fig.11: Instantaneous Voltage at AC bus

Fig.11 shows the output voltage wave forms of an cascaded h-bridge five level inverter in which the pv voltage is converted to ac voltage.

V. Conclusion

PV-battery based hybrid power generation system for residential application is presented in this paper. Voltage quality is maintained with respect to changes in load and solar irradiance. Proper controllers are designed and achieved proper energy management between various sources and load. Battery is connected through dc-dc bidirectional convert to improve the power quality with respect to changes in solar irradiance and load. P&O algorithm is incorporated to controller of dc-dc bidirectional converter which is connected between dc bus and battery. Hence, dc-dc converter acts as MPPT converter for PV. Therefore, extra circuit is not required to extract the maximum power from PV. DSTATCOM is connected to AC bus to improve voltage quality as well as reactive power compensation. Also a five level multilevel inverter is designed with its advanced PWM technique in order to improve the quality. From results one can observe system maintained good power quality in all the possible conditions.

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DOI: 01.IJEPE.4.3.1337